Role of asymmetry of the reaction and momentum dependent interactions on the balance energy for neutron rich nuclei

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Introduction

A large number of next-generation radioactive beam facilities are being constructed or planned in addition to many already existing facilities in the world. At these facilities, nuclear reactions involving nuclei with a large neutron or proton excess can be studied, thus providing a great opportunity to study both the structure of rare isotopes and the properties of isospin asymmetric nuclear matter. Complementary to the nuclear structure studies but being equally important and exciting are reaction studies with radioactive beams, especially heavy-ion reactions induced by neutron-rich beams at intermediate energies. The ultimate goal of this branch of nuclear physics is to determine the isospin dependence of the in-medium nuclear effective interactions and the equation of state (EOS) of isospin asymmetric nuclear matter, particularly its isospin-dependent term, i.e., the density dependence of the nuclear symmetry energy. One has also to look for the ovservables which are sensitive to the symmetry energy since it can not be measured directly from experiments. Collective transverse in-plane flow as well as its disappearance has been found to be the one of the most sensitive observables to dynamics of heavy-ion collisions at intermediate energies [1]. In recent study Gautam et al., [2] has found that in-plane flow is sensitive to symmetry energy as well as its density dependence. Moreover the sensitivity to symmetry energy increases with increase in neutron content of the system. Here we present a systematic study of disappearance of flow i.e. balance energy E_{bal} for an isotopic series of Ca with N/Z varying from 1 to 2 for different density dependences of symmetry energies. We also extend this study for asymmetric reactions having radioactive projectile and stable target. The present study is carried out using IQMD model [3].

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Results and Discussion

We have simulated several thousand events at incident energies around balance energy in small steps of 10 MeV/nucleon for each isotopic system of Ca+Ca having N/Z (N/A) varying from 1.0 to 2.0 (0.5-0.67). To check the sensitivity of N/Z (N/A) dependence of E_{bal} towards density dependence of symmetry energy, we have calculated the E_{bal} throughout the isotopic series for different forms of symmetry energy The various forms are $F_1(u) \propto u$, $F_2(u) \propto u^{0.4}$, $F_3(u) \propto u^2$ where $u = \frac{\rho}{\rho_0}$ In fig. 1a (b) we display the N/Z (N/A) dependence of E_{bal} fir symmetric reactions of Ca isotops with N/Z (N/A) varying from 1-2 (0.5-0.67) for different forms of symmetry energy; F_1(u) (solid circles), F_2(u) (diamonds), and F_3(u) (pentagons). For all the cases E_{bal} follows a linear behavior. Clearly, N/Z (N/A) dependence of E_{bal} is sensitive to the density dependence of symmetry energy. We also note that for a fixed N/Z (N/A) stiff symmetry energy F_1(u) shows less E_{bal} as compared to soft F_2(u) whereas super stiff symmetry energy F_3(u) shows more E_{bal} as compared to F_2(u). For detailed discussion on this we refer to [4] Since one cannot use radioactive iso-

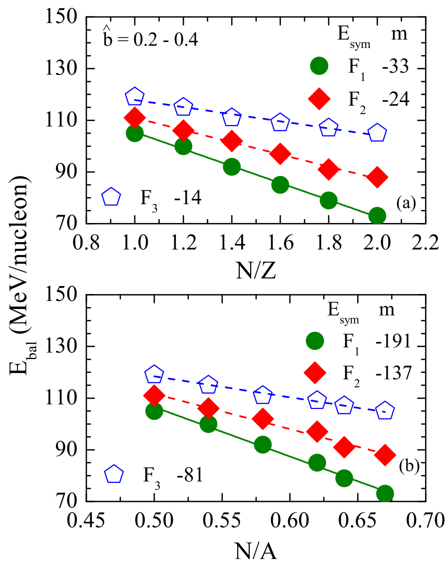

FIG. 1: E_{bal} as a function of N/Z (upper panel) and N/A (lower panel) of system Various lines and symbols are explained in the text.

topes as targets, therefore, as a next step we fix the target as a stable isotope ^{40}Ca and vary the projectile from ^{40}Ca to ^{60}Ca and calculate E_{bal}. In this case the N/Z (N/A) of the reaction varies between 1 to 1.5 (0.5 to 0.6) and the asymmetry $\delta = \frac{A_1 - A_2}{A_1 + A_2}$ of the reaction varies from 0 to 0.2. The results are displayed by solid green stars in figs. 2(a) and (b) (upper panels). The solid green circles represent the calculations for symmetric reactions. Lines represent the linear fit $\propto$ m. We see that N/Z (N/A) dependence of E_{bal} is same for both the cases. We also find that as the N/Z (N/A) decreases from 2 (0.67) in case of ^{60}Ca+^{60}Ca to 1.5 (0.6) for ^{60}Ca+^{40}Ca, the E_{bal} also decreases accordingly. Now the E_{bal} for ^{60}Ca+^{40}Ca has same value as in case of symmetric reactions with N/Z (N/A) = 1.5 (0.6) i.e. the value of E_{bal} is decided by the N/Z (N/A) of the system and is independent of the asymmetry of the reaction. It has also been reported in literature that the momentum dependent interaction (MDI) affects dras-

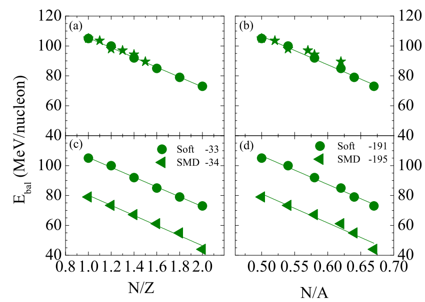

FIG. 2: E_{bal} as a function of N/Z (left panel) and N/A (right panel) of system. Various lines and symbols are explained in the text.

tically the collective flow as well as its disappearance [5]. To check the influence of MDI on the N/Z (N/A) dependence of E_{bal} we calculate the E_{bal} for the whole N/Z (N/A) range from 1 to 2 (0.5 to 0.67) for the symmetric reactions with SMD equation of state and symmetry potential $F_1(u)$. The results are shown in figs. 2(c) and (d) (lower panels) by solid left triangles. We find that although the MDI changes drastically the absolute value of E_{bal} (by about 30%), however the N/Z (N/A) dependence of E_{bal} remains unchanged on inclusion of MDI. Therefore, the dependence of E_{bal} as a function of N/Z (N/A) on the symmetry energies of other different forms ($F_2(u)$ and $F_3(u)$) is also expected to be preserved on inclusion of MDI.

Acknowledgments

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